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COMPREHENSIVE ENVIRONMENTAL INCORPORATED

TECHNICAL MEMORANDUM

To: Ray Cody and Karen Simpson, United States Environmental Protection Agency, Region 1

From: Ken Hickey and Don Galya, WaterVision

Subject: **Brief Literature/Technology Review of Nitrogen Removal Best Management Practices**

Date: February 19, 2015

This memo provides a summary of a brief literature and technology review of nitrogen removal Best Management Practices (BMPs) conducted in support of the Cape Cod BMPs project. The review included a cursory analysis of the types of stormwater BMPs commonly used and recommended in state and regional stormwater BMP guidance documents with focus on nitrogen-removal performance. Stormwater BMP monitoring program data were also evaluated to assess the performance of various types of BMP in removing nitrogen. Lastly, the University of New Hampshire Stormwater Center (UNHSC)'s Tedeschi bioretention system and related subsurface gravel wetland systems were reviewed.

State and Regional Stormwater BMPs Guidance Documents

A cursory review of state and regional stormwater guidance manuals was conducted to support assessment of the use of nitrogen-removal BMPs in New England and around the United States. The review included stormwater guidance manuals from the following New England states:

- Massachusetts (MADEP, 2008)
- Rhode Island (RIDEM, 2010)
- Connecticut (CTDEP, 2004)
- New Hampshire (NHDES, 2008)

Table 1 provides a compilation of types of stormwater BMPs with estimated ranges of total nitrogen removal from four New England state stormwater manuals. Massachusetts and New Hampshire provide numerical nitrogen removal ranges, while Rhode Island and Connecticut provide qualitative assessments of performance. In general, several types of stormwater BMPs were stated as providing nitrogen removal, with treatment BMPs, conveyance BMPs, and infiltration BMPs most frequently sited. Bioretention areas and rain gardens, constructed stormwater wetlands, sand and organic filters, and infiltration basins and trenches were described by all four states as providing nitrogen removal. Wide ranges of nitrogen removal performance (0 to 90%) were provided in the four New England stormwater BMP manuals reviewed.

Subsurface gravel wetlands (SGWs) are of particular interest due to the relatively high nitrogen removal efficiencies reported for these BMPs. Several New England states include SGWs in their stormwater manuals and, in all cases, report the UNHSC's monitoring results. Other states and organizations, including the New Jersey Department of Environmental Protection and the Center for Watershed Protection include SGWs in their stormwater guidance documents.

Table 1. Compilation of Total Nitrogen Removal Efficiencies by Type of BMP from Selected Stormwater Manuals

Type of BMP	Massachusetts	Rhode Island	Connecticut	New Hampshire
Structural Pretreatment BMPs				
Deep Sump Catch Basin				5%
Proprietary Separators			Partial Benefit	10%
Vegetated Filter Strips			Partial Benefit	40%
Treatment BMPs				
Bioretention Areas and Rain Gardens	30-50% *	Good	Sig. Benefit	65%
Constructed Stormwater Wetlands/Wet Vegetated Treatment Systems (includes gravel wetlands)	20-55%	Good	Sig. Benefit	55-85%
Stormwater Ponds			Sig. Benefit	35-55%
Vegetated Buffers				40%
Extended Dry Detention Basins	15-50%			
Sand and Organic Filters	20-40%	Good	Sig. Benefit	10-60%
Wet Basins	10-50%	Good		
Conveyance BMPs				
Grass Drainage Channels			Partial Benefit	
Water Quality Swale	10-90%	Good	Partial Benefit	
Infiltration BMPs				
Infiltration Basins	50-60%	Fair	Sig. Benefit	10-60%
Infiltration Trenches	40-70%	Fair	Sig. Benefit	10-55%
Subsurface Structures		Fair		
Underground Infiltration Systems			Partial Benefit	
Dry Wells		Fair	Partial Benefit	55%
Other BMPs				
Dry Detention Basin	5-50%			
Green Roofs		Good		
Porous Pavement		Good	Partial Benefit	10-60%

Notes: Blank cells indicate either not assessed, poor removal, or insufficient data

* In Massachussetts manual, stated nitrogen removal is dependent on soil media > 30"

Monitoring Data on Total Nitrogen and Nitrate Reduction Associated with Stormwater BMPs

Data on the capability of various treatment technologies to reduce the nitrogen content in stormwater were obtained from specific site studies (e.g. Hunt et al. 2006), agency stormwater BMP guidance manuals (e.g. Seattle Public Utilities, 2009), and compilations of data from site-specific studies (e.g., CWP, 2007). A compilation of percent total nitrogen and nitrate removal for various stormwater BMPs is provided Table 2.

Bioretention, constructed wetlands, swales, retention, detention, infiltration, and subsurface gravel wetlands appear to have the potential for at least some effectiveness at total nitrogen reduction, with detention/dry ponds being the least effective (Table 2). Substantial reductions in total nitrogen (>70%) have been measured in all of the other technologies. Total nitrogen reduction for several of the conventional technologies, particularly swales and infiltration, is likely due to filtering of sorbed and/or particulate nitrogen. Similarly, the types of BMPs compiled in Table 2 have been measured to efficiently remove nitrate.

In evaluating nitrogen removal of various types of BMPs, it is worthwhile to note that there is a very wide range, from 100% to -100%, in total nitrogen reduction for all of the conventional technologies. For example, the Center for Watershed Protection (2007) database shows that some of the conventional technologies (bioretention, constructed wetlands, retention/wet ponds, detention/dry ponds) include negative removal values, representing an increase in total nitrogen associated with the BMP. The increase is likely due to flushing of dissolved, particulate, and/or sorbed nitrogen from soils or sediments within the BMP.

Koch (2014) compiled monitoring data on removal of various forms of nitrogen from dry ponds, wet ponds, constructed wetlands, and swales (Figure 1) and found that constructed wetland systems achieved the most consistently positive nitrogen removal.

In the compilation in Table 2, subsurface gravel wetlands were the only BMP type that had a minimum of 36% total nitrogen removal in all measurements. SGWs also had the most consistently high nitrate reduction values. Each of the other BMP types had total nitrogen removal measurements of 0 or less in some cases. The anaerobic design component featured in SGWs are expected make this technology highly effective at nitrate reduction and this appears to be demonstrated by the data.

The relatively high nitrate reduction potentially achieved by the conventional technologies without a specific anaerobic design component might be somewhat surprising. A possible explanation for this is the presence of anaerobic zones in soils and/or sediments in the treatment cells. Hunt et al. (2006) states such a hypothesis for this phenomenon, as well as the observed wide range in nitrate reduction values, in a study report of two bioretention sites in North Carolina:

> *"…NO3-N loads were reduced by varying degrees by the two conventionally designed cells. Greensboro cell G2 removed 75%, while Chapel Hill cell C1 removed 13%. This may have been due to the possible formation of an anaerobic zone in G2 and not in C1."*

Table 2: Total Nitrogen (TN) and Nitrate (NO3) Reduction for Various Stormwater BMPs

BMP Study/Manual/Reference	% TN Reduction	% NO3 Reduction
Bioretention		
CWP Database (CWP, 2007) Median (Min- Max)	46 (-2 - 61)	43 (0 - 76)
Seattle 110th Street Catchment (Horner and Chapman, 2007)	53 - 74	-
PA Stormwater BMP Manual (PA DEP, 2006)	-	30
UNH Bio Test Sites (UNH 2012; Roseen and Stone, 2013)	24	42 - 44
NC Field Sites (Hunt 2003; Hunt et al. 2006)	40	13 - 75
Planimetrics and Trinkaus Engineering, 2011	17 - 60	44 - 60
Constructed Wetlands		
CWP Database (CWP, 2007) Median (Min- Max)	24 (-49 - 76)	67 (-100 - 99)
MD Stormwater Wetland (CWP Article 89)	22.8	54.5
PA Stormwater BMP Manual (PA DEP, 2006)	-	30
Planimetrics and Trinkaus Engineering, 2011	56 - 80	35 - 80
Koch, et al., 2014 (*estimated values from Fig. 2)	5 - 90*	-10 -98*
Swales		
CWP Database (CWP, 2007) Median (Min- Max)	56 (8 - 99)	39 (-25 - 99)
PA Stormwater BMP Manual (PA DEP, 2006)	-	20
Planimetrics and Trinkaus Engineering, 2011	0 - 40	0 - 41
Portland, OR Test Swales (Liptan and Murase, 2002)	-	8 - 16
Koch, et al., 2014 (*estimated values from Fig. 2)	40 - 55*	20- 70*
Retention/Wet Ponds		
CWP Database (CWP, 2007) Median (Min- Max)	31 (-12 - 76)	45 (-85 - 97)
PA Stormwater BMP Manual (PA DEP, 2006)	-	30
UNH Stormwater Center, 2012 Biennial Report	-	33
Planimetrics and Trinkaus Engineering, 2011	35	36
Koch, et al., 2014 (*estimated values from Fig. 2)	-5 - 70*	-100 - 100*
Detention/Dry Ponds		
CWP Database (CWP, 2007) Median (Min- Max)	24 (-19 - 43)	9 (-10 - 79)
PA Stormwater BMP Manual (PA DEP, 2006)	-	20
UNH Stormwater Center, 2012 Biennial Report	-	25
Planimetrics and Trinkaus Engineering, 2011	0	33
Koch, et al., 2014 (*estimated values from Fig. 2)	-10 - 55*	-90 - 70*
Infiltration		
CWP Database (CWP, 2007) Median (Min- Max)	42 (0 - 85)	0 (-100 - 100)
PA Stormwater BMP Manual (PA DEP, 2006)	-	30
Planimetrics and Trinkaus Engineering, 2011	60	50
Subsurface Gravel Wetlands		
UNH Stormwater Center, 2012 Biennial Report	50 - 70	75
UNH Durham, NH Study (Roseen and Stone, 2013)	36	60
Ocean County, NJ - 10 Sites (Skupien 2013)	-	52 - 75

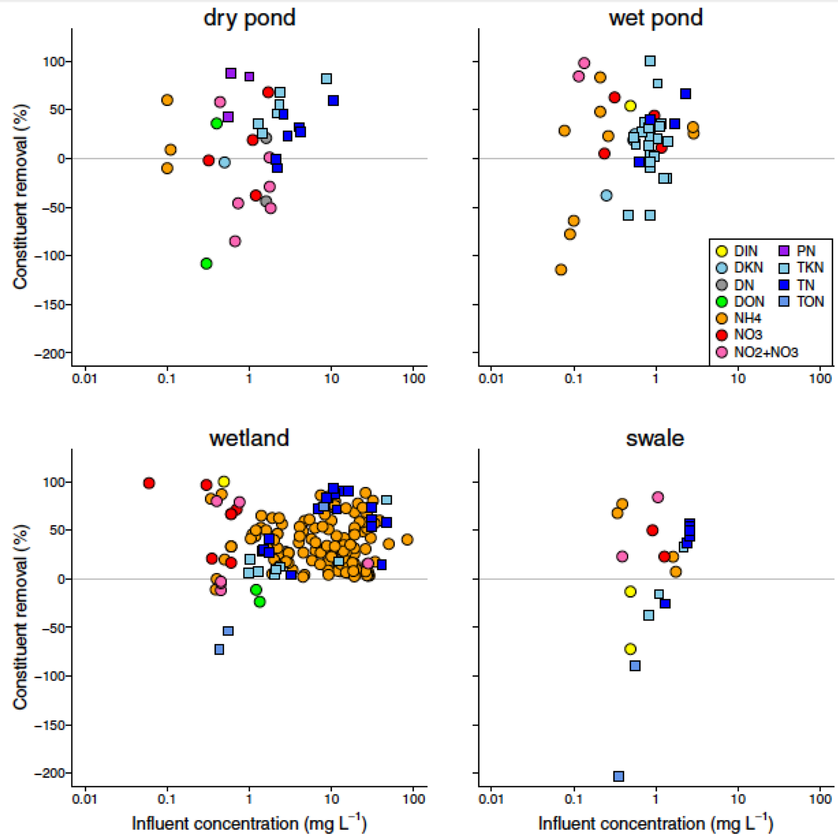

FIGURE 1. Nitrogen (N) Removal Efficiency and Concentration for Constituents in Water Flowing into Dry Ponds, Wet Ponds, Wetlands, and Swales. Data are from a comprehensive synthesis of empirical studies of stormwater best management practice (SW BMP) performance measured over time scales of hours to weeks. Over those time periods, stormwater management structures were generally effective (removal efficiency > 0) but highly variable in removing N across a wide concentration range. Solid gray lines denote no net effect of SW BMPs on N levels. DIN, dissolved inorganic nitrogen; DKN, dissolved Kjeldahl nitrogen; DN, dissolved nitrogen; DON, dissolved organic nitrogen; NH_4, ammonium; NO_3, nitrate; NO_2 + NO_3, nitrite + nitrate; PN, particulate nitrogen; TKN, total Kjeldahl nitrogen; TN, total nitrogen; TON, total organic nitrogen. One outlier (NO_3) does not appear on the wetland panel: 0.54 mg/l, −794%.

Figure 1. Nitrogen Removal Efficiency and Concentrations associated with Four Types of BMPs (Koch 2014)

Koch et al. (2014) also make the following pertinent observations about nitrogen removal by conventional stormwater BMPs, based on a review of constructed wetlands, dry and wet ponds, and swales:

- Multiple BMP treatment units installed in series may provide better nitrogen removal compared to single treatment units. (The increased performance of multiple units is reflected in the VA DCR guidance documents listed in the References section below.)
- Older BMP treatment units appear to have decreased performance. Maintenance may prevent a decline in performance - but maintenance is not commonly performed.
- The data reflecting considerable variability in nitrogen removal by conventional technologies should be considered in BMP treatment system design. Increased monitoring, coupled with information on BMP design parameters, may provide additional insights into the reasons for the high variability in performance.

In summary, the data appear to demonstrate that subsurface ravel wetlands provide the most consistently reliable reduction in nitrogen, especially nitrate, in stormwater. Nevertheless, conventional technologies also have the potential for achieving effective nitrogen removal. BMP design should consider the high variability in previous measurements of nitrogen removal, the potential for increased performance using a series of treatment units, and system maintenance to continue to achieve the maximum possible performance.

UNHSC Tedeschi Bioretention System

In 2011, a bioretention system was constructed in a Tedeschi convenience store parking lot in Durham, New Hampshire (Roseen and Stone, 2013). The Tedeschi bioretention system design was modeled after a UNHSC subsurface gravel wetland system and featured nitrogen removal through anaerobic treatment. The performance of the UNHSC subsurface gravel wetland system was monitored for 8 years (2004 – 2010) and has been found to remove 50 to 70% total nitrogen (TN) (UNHSC, 2012). The performance of the Tedeschi system was monitoring beginning immediately after construction in fall of 2011 for a period of one year. Limited nitrogen removal data were collected and resulted in an estimated removal of 36% of TN for the Tedeschi system.

On November 19, 2014, we met with James Houle and Tom Ballestero of the UNHSC and discussed the Tedeschi system and nitrogen-removal BMPs in general. UNHSC staff confirmed that the Tedeschi bioretention system was a subsurface gravel wetland system that had been modified to fit into a constrained, parking lot island location. At the Tedeschi site, the treatment chambers were arranged in an "above-below" configuration rather than the usual side-by-side layout. The conceptual approach to nitrogen removal was the same for the Tedeschi system and for typical subsurface gravel wetland systems. Dr. Ballestero stated that the nitrogen-removal efficiency of different configurations of subsurface gravel wetland systems (such as the Tedeschi system) may be good, but are unknown because only the typical design has been extensively monitored. Several factors are important to successful subsurface wetland design including residence time and the ratio of water quality volume to internal storage reservoir. These and other factors were discussed at length during the meeting and in subsequent BMP design discussions.

UNHSC staff stated that several problems had occurred with regard to the monitoring program at the Tedeschi site. The primary problem was that the BMP system had been monitored too soon after construction. Subsurface gravel wetland systems require seeding of microbes to perform stormwater treatment. These microbes require time to become established and to become fully functional at removing nitrogen and other pollutants. UNHSC staff recommended that subsurface gravel wetland systems should not be monitored during the first year or so until they become fully functional.

In summary, the Tedeschi bioretention system is a form of a subsurface gravel wetland and has been subject to insufficient monitoring to support evaluation of success in removing nitrogen. Conceptually, it appears likely that the Tedeschi system would perform similarly to the UNH subsurface gravel wetland system in removing nitrogen (i.e. 50% to 70% TN removal). It also appears likely that other configurations of subsurface gravel wetlands system would perform well at nitrogen removal provided that key factors were properly specificied.

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